

Methodology of designing an air cascade separator

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Abstract. The calculation technique of industrial cascade separators based on experimental and analytical research process methods for air fractionation of bulk materials is considered. The main technological factors and process defining parameters used in calculation of separator design are presented. It is shown that for the design of an industrial separator, it is necessary to find a relationship between the initial granulometric distribution and the fractional requirements for the finished product from the concentration of the material flow and the air flow velocity to the complete cross-section of the separator. The experiment results of material flow concentration influence on division efficiency for various cascade separator constructions are given. Mathematical relationship of the air flow rate through the apparatus on the separation boundary and bulk concentration is proposed. The correlation of these parameters with the constructive sizes of the separator is shown. The initial particle size distribution of bulk, the set restrictions for fractional characteristics of the received powder and the approximating equations of fractional extraction function of fineness narrow classes in a large or small product based on experimental data are used for calculation of the equipment.

1. Introduction

Cascade air separators are widely used for solving various production tasks [1–7] related to processing and enrichment of bulk materials. This is because by their high efficiency of division [8] and ability to get fractions powdery materials in wide borders with low power expenses. To a large extent, their implementation at enterprises is difficult because of the low popularity of design techniques for such devices, the complexity of the transition from the mathematical model of the process to the overall dimensions and technological characteristics of the equipment. This problem is resolved in this paper.

2. Design technique

In our opinion, the most common at present are three types of cascade pneumatic separators: single-column separators with various bulk elements; multi-row separators combined over a common perforated grate and separators with an inclined grate.

In all cases, the structural analysis comes down to determining the cross-sectional area of separator or lattice. It was shown in [9] that separator efficiency increase practically stops if the number of cascades exceeds 6–7 units. For one-column separator this value is 6–7 pour out elements, for a combined one – 6 or 7 columns with the same number of overturning shelves. Knowledge of the area of one cell cascade allows us to determine the overall separator dimensions. The dimensions of inclined separator can be easily defined with knowledge of the grille cross-sectional area [9].

For given initial supply capacity Q and known flow concentration μ , it is possible to calculate the separator air flow V :



$$V = \frac{Q}{\mu} \quad (1)$$

In turn, the cross-sectional area S of the separator (grille) is defined as:

$$S = \frac{V}{w} \quad (2)$$

where w is velocity of the air flow to the total cross section of the separator or grille.

The flow concentration determines the ratio of the bulk material amount passing through the installation and the air flow, which in turn sets the dimensions of separator and associated equipment, and also the energy consumption per ton of the product obtained.

The optimum concentration value is the maximum value at which the requirements for the product are met, while observing the limitations on the "loss" of the valuable fraction (component) with the waste.

Therefore, to design an industrial separator, it is necessary to find the relationship between initial particle-size distribution and fractional requirements for the finished product from flow concentration of material and speed of the air flow to the total cross section of the separator.

Universal characteristic of the bulk material separation process is the function $F_{sm}(x_i)$ for fractionally extracting narrow classes x_i into a fine product or the backward Tromp curve [10].

Knowing the function of fractional extraction, it is possible to determine the content of any fraction in fine or coarse product [2]:

$$r_{smi} = \frac{F_{sm}(x_i)r_{ini}}{\gamma_{sm}}; \quad (3)$$

$$\gamma_{sm} = \sum_i F_{sm}(x_i)r_{ini}; \quad (4)$$

$$r_{ci} = \frac{r_{ini} - r_{smi}\gamma_{sm}}{1 - \gamma_{sm}}, \quad (5)$$

where r_{ini} , r_{smi} , r_{ci} – the content of the i -th fraction in the initial, fine or coarse product;

γ_{sm} – is the output of fine material.

The function of fractional extraction is characterized by two main indicators – the x_{50} separation boundary and the magnitude of effectiveness. To calculate the separation efficiency, for example, the Eder-Mayer point test $k_{75/25}$ [8, 10] is widely used. The function of fractional extraction can be approximated, for example, by the two-parameter Rosina-Ramler function [11]:

$$F_{sm}(x_i) = \exp\left(-\ln 2 \left(\frac{x_i}{x_{50}}\right)^p\right) \quad (6)$$

or Plitte function [11]:

$$F_{sm}(x_i) = \frac{1}{1 + \left(\frac{x_i}{x_{50}}\right)^p}, \quad (7)$$

and the exponent p is expressed in terms of $k_{75/25}$.

For the Plitte function [8]:

$$k_{75/25} = \left(\frac{1}{9}\right)^{\frac{1}{p}}. \quad (8)$$

For the Rosina – Ramler function:

$$k_{75/25} = \left(\frac{\ln 0,75}{\ln 0,25} \right)^{\frac{1}{p}}. \quad (9)$$

It is possible to model the fractionation process and calculate the parameters p and x_{50} by the selection method [11], using the formulas (3–5) and one of the approximations (6 or 7).

In [8, 9], the effect of the flow concentration on the separation boundary and efficiency by the Eder-Mayer criterion was investigated. It is noted that the efficiency curve has a certain zone of constancy and then a monotonic decrease with concentration increasing. Figure 1 shows a graph of the parameter p dependence on the flow concentration μ by the combined multi-row separator when fractionating the technical salt. The inverse relationship will have the form Figure 2.

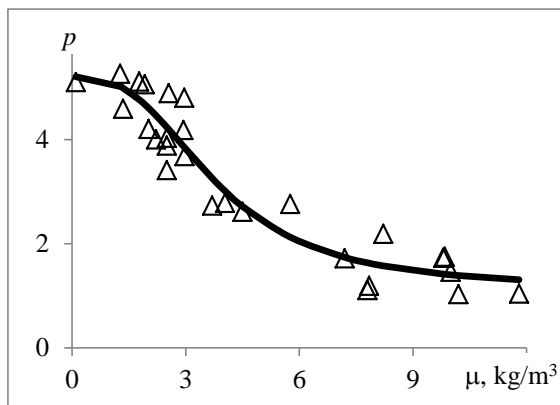


Figure 1. Dependence of the approximation parameter p of the Plate on the flow concentration.

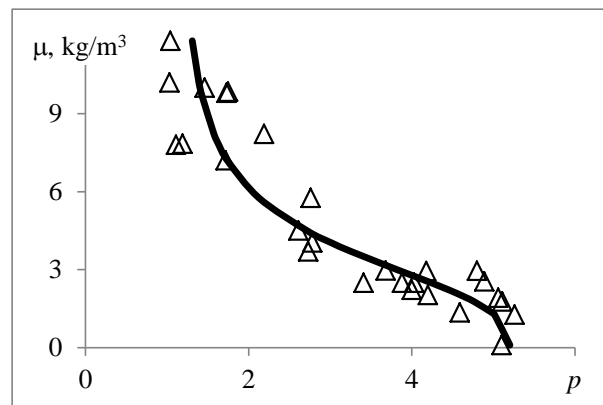


Figure 2. Dependence of the flow concentration on the parameter p of the Plitt approximation.

A mathematical approximation of this relationship looks like:

$$\mu = 3,82 \left(\frac{4,07}{p - 1,14} \right)^{\frac{1}{2,75}}. \quad (10)$$

Similar dependencies can be obtained for any other material on the laboratory model of the projected cascade separator. The separation boundary in the bulk material fractionation depends not only on the flow concentration, but also on the gas flow rate in the square

$$x_{50} = f(\mu, w^2). \quad (11)$$

Taking into account the analysis of dimensions, it is possible to propose an investigation of the following dependence

$$\frac{x_{50}g}{w^2} = f(\mu). \quad (12)$$

The Figure 3 shows the dependence of the parameter $\frac{x_{50}g}{w^2}$ on the flow concentration, which can be approximated by a parabola

$$\frac{x_{50}g}{w^2} = 4 \cdot 10^{-5} \mu^2 + 8 \cdot 10^{-4} \mu. \quad (13)$$

Separating the flow velocity from [equation (14)], we obtain

$$w = \sqrt{\frac{x_{50}g}{4 \cdot 10^{-5} \mu^2 + 8 \cdot 10^{-4} \mu}} = P(x_{50}, \mu). \quad (14)$$

If you calculate the parameter for experimental values of the flow rate, you can draw a graph (Figure 4).

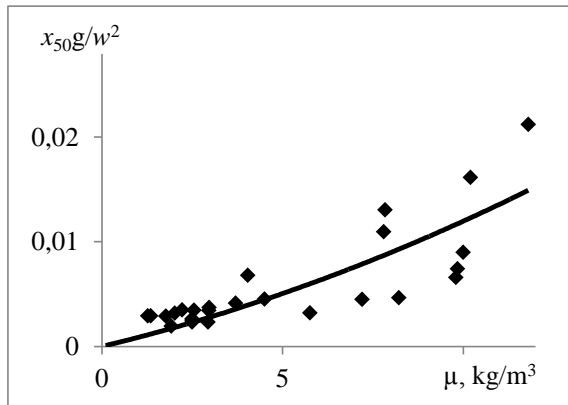


Figure 3. Dependence of the parameter $\frac{x_{50}g}{w^2}$ on the flow concentration.

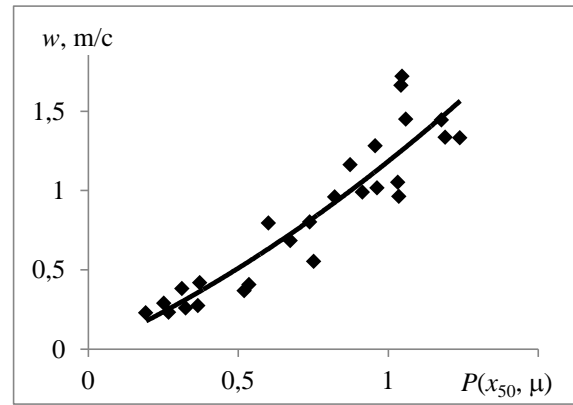


Figure 4. The dependence of the flow velocity on the parameter $P(x_{50}, \mu)$.

Finally, the equation can be written as

$$w = \frac{0,33x_{50}g}{4 \cdot 10^{-5} \mu^2 + 8 \cdot 10^{-4} \mu} + 0,86 \sqrt{\frac{x_{50}g}{4 \cdot 10^{-5} \mu^2 + 8 \cdot 10^{-4} \mu}}. \quad (15)$$

3. Conclusion

Thus, it is possible to list the main stages of calculating the cascade pneumatic separator:

1. The mathematical model of the process of fractionation of bulk materials should be developed taking into account the requirements for the finished product. To calculate the fractional extraction function, we use formulas (6) or (7). Calculations are more conveniently carried out in the form of table 1

Table 1. Powder fractionation process model.

Fraction size x_i	r_{ini}	$F_{sm}(x_i)$	$F_{sm}(x_i)r_{ini}$	r_{smi}	r_{ci}
x_1	r_{in1}	$F_{sm}(x_1)$	$F_{sm}(x_1)r_{in1}$	r_{sm1}	r_{c1}
...
x_n	r_{inn}	$F_{sm}(x_n)$	$F_{sm}(x_n)r_{inn}$	r_{smn}	r_{cn}
Output $\gamma_{sm} \quad \Sigma F_{sm}(x_i) r_{ini}$					

Determine the x_{50} separation boundary and the parameter p ensuring the production of the desired product, using the computer selection method.

2. Calculate the dependence of separation efficiency with the Eder-Mayer criterion on the flow concentration, according to laboratory experiment data.

3. Find the required value of material flow concentration, at which the p parameter value turns out to be no less than calculated by the mathematical model (Section 1).

4. Using laboratory experiment data and calculated flow concentration, we find the velocity of the air flow to the total cross section of the separator (grille).

5. Calculate the flow rate of air flow through the separator, the overall dimensions of the installation. Make selection of additional equipment and air blower.

If it is necessary to improve the efficiency of the separation, it is possible to compose a technological scheme with several clearings.

The results of this methodology have been successfully tested in the calculation and implementation of cascade separators at various industrial enterprises [2–4, 7, 12, 13].

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